Parton Energy Loss with Detailed Balance [*]

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In this Letter, we report a first study of the effect of stimulated emission and thermal absorption on the energy loss of a propagating parton in a hot QCD medium. We consider both the final-state radiation associated with the hard processes that have produced the original hard parton and the radiation induced by final-state multiple scattering in the medium. Naively, the energy scale associated with stimulated emission and thermal absorption should both be around the temperature of the medium, $\omega \sim T$. However, we will show in this Letter that the partial cancellation between stimulated emission and thermal absorption results in a net reduction of parton energy loss induced by multiple scattering. The relative reduction decreases with the parton energy E as T/E, as a consequence of the LPM interference. Though such a reduction is negligible for asymptotically large parton energy, it is still important for intermediate values of E. It also modifies the energy dependence of the total energy loss in the small to intermediate energy region, which is very relevant to the jet quenching phenomenon for intermediate large $p_T < 10$ GeV/c hadrons.

Even though the stimulated emission cancels part of the contribution from absorption, the net medium effect without rescattering is still dominated by the final-state thermal absorption, resulting in a net energy gain, *i.e.* a *negative* energy loss. For asymptotically large parton energy, $E \gg T$, one has,

$$\frac{\Delta E_{abs}^{(0)}}{E} \approx -\frac{\pi \alpha_s C_F}{3} \frac{T^2}{E^2} \left[\ln \frac{4ET}{\mu^2} + 2 - \gamma_E + \frac{6\zeta'(2)}{\pi^2} \right], \quad (1)$$

where, $\gamma_E \approx 0.5772$ and $\zeta'(2) \approx -0.9376$. Terms that are proportional to $\exp(-E/T)$ or beyond the order of $(T/E)^2$ are neglected. The quadratic temperature dependence of the leading contribution is a direct consequence of the partial cancellation between stimulated emission and thermal absorption, each having a leading contribution linear in T.

Similarly to the case of final-state absorption, one can also include stimulated emission and thermal absorption when calculating the radiation energy loss,

$$\frac{\Delta E_{rad}^{(1)}}{E} \approx \frac{\alpha_s C_F \mu^2 L^2}{4\lambda_g E} \left[\ln \frac{2E}{\mu^2 L} - 0.048 \right], \quad (2)$$

$$\frac{\Delta E_{abs}^{(1)}}{E} \approx -\frac{\pi \alpha_s C_F}{3} \frac{LT^2}{\lambda_g E^2} \left[\ln \frac{\mu^2 L}{T} - 1 + \gamma_E - \frac{6\zeta'(2)}{\pi^2} \right]. \quad (3)$$

Again, the thermal absorption results in an energy gain (or negative energy loss). Our analytic approximation of the GLV zero-temperature result also agrees with the improved limit by Zakharov. However, our result is accurate through the order of $1/E$. In Eq. (3), we have assumed $\mu^2 L/T \gg 1$ and kept only the first two leading terms. In this limit, the average formation time for stimulated emission or thermal absorption is much smaller than the total propagation length. Therefore, the energy gain, $\Delta E_{abs}^{(1)}$, by thermal absorption (with partial cancellation by the stimulated emission) is linear in L, as compared to the quadratic dependence in the zero-temperature case. However, the logarithmic dependence on $\mu^2 L/T$ as compared to the factor $\ln(4ET/\mu^2)$ for no rescattering is still a consequence of the LPM interference in medium. A quadratic L-dependence of $\Delta E_{abs}^{(1)}$ will arise when $\mu^2 L/T \ll 1$.

Even with partial cancellation by stimulated emission, the net result is an energy gain via absorption which reduces the effective parton energy loss. Such a reduction is found to be important for intermediate parton energy but can be neglected at very high energies. For large distance $\mu^2 L/T \gg 1$, we find that the energy gain due to induced absorption with rescattering is linear in L, *modulo* a logarithmic dependence.